FIRE DETECTION STUDIES IN THE CONVAIR-340 POWER PLANT

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FIRE-DETECTION STUDIES IN THE CONVAIR-340 POWER PLANT*

SUMMARY

Tests were conducted in an operating full-scale Convair-340 airplane nacelle to evaluate the fire-detector system currently used in operational aircraft of this type. The results indicated that the Zone 1 portion of the system could be greatly improved by relocating some detector units and by adding four others. The Zone 2 portion of the system was found adequate, and the only change recommended as a result of the tests was the relocation of two detector units to improve the over-all efficiency. Since the test installation did not include a representative Zone 3, the portion of the system occupying that zone was not evaluated.

INTRODUCTION

United Air Lines, Consolidated Vultee Aircraft Corporation, and the Technical Development and Evaluation Center of the Civil Aeronautics Administration collaborated in a program to evaluate the fire safety of the Convair-340 airplane power plant. United Air Lines supplied an engine-and-propeller assembly, Convair supplied a nacelle and assistance in assembling the parts into an operating power plant, and TDEC supplied the test facilities and equipment as well as the personnel to conduct the tests. Testing was started in November 1952 and was intentionally limited to the engine and accessory sections (Zones 1 and 2) because, by design, fires occurring in flight in either zone are intended to be confined to that zone. Zone 3 was simply enclosed, it was not representative of Zone 3 in operational aircraft and it did not contain landing gear. However, it was protected by the airplane detector and extinguishing systems.

This report is concerned with an evaluation of the unit type of fire-detection system as it was normally installed in Convair-340 operational aircraft and the modifications to the system which the tests indicated are highly desirable. Much of the information contained in this report should be generally applicable to other aircraft.

DESCRIPTION OF TEST EQUIPMENT

The fire-detection evaluation tests were conducted in a Convair CV-340 left-hand nacelle. The right-hand nacelle differs from the left principally in its accessory section, which contains the cabin supercharger. All of the usual accessories required for the left-hand nacelle were included, but only the fuel pump, engine starter, and tachometer generator were functioning. Such other accessories as the water-injection regulator, hydraulic pump, and generator were inoperable. The propeller, a Hamilton Standard hydromatic, Model 43E60-3, was driven by a Pratt & Whitney R-2800-CB16 engine. Normally, the engine used in the CV-340 has a single-stage, two-speed supercharger, but this engine was not equipped with the supercharger selector valve or clutch assembly. Gears were used to drive the supercharger in the "low blower" stage.

The test nacelle was mounted on a box truss which in turn was supported by columns. Controls were located in small buildings at each side of the nacelle. See Fig. 1. The building at the left in this photograph contained temperature-recording potentiometers, a Rectox unit which supplied 30 volts d-c, and a switch panel for the a-c power. The building at the right contained the engine-control panel, cylinders of carbon dioxide for the stand-by extinguishing system, a 400-cps single-phase inverter, a sequence recorder, and the amplifiers for the Edison fire-detection system.

A mobile air-blast unit was used to provide cooling air for the test engine and to simulate flight conditions. The unit consisted of an Allison V-3420 aircraft reciprocating engine driving two Aeroproducts counterrotating propellers through a gear box. The propellers, originally the tractor type, were modified to the pusher type for this application. Air speeds up to 120 mph were obtainable.

To provide fires for the tests, three fire nozzles were fabricated, each of which could be used as an independent source of fire. The use of three nozzles made it possible to start fires at three separate locations, one after another, while one set of operating conditions prevailed. It also made it possible to continue operation for longer periods before having to shut down in order to move the nozzles to new locations. Each nozzle produced a spray

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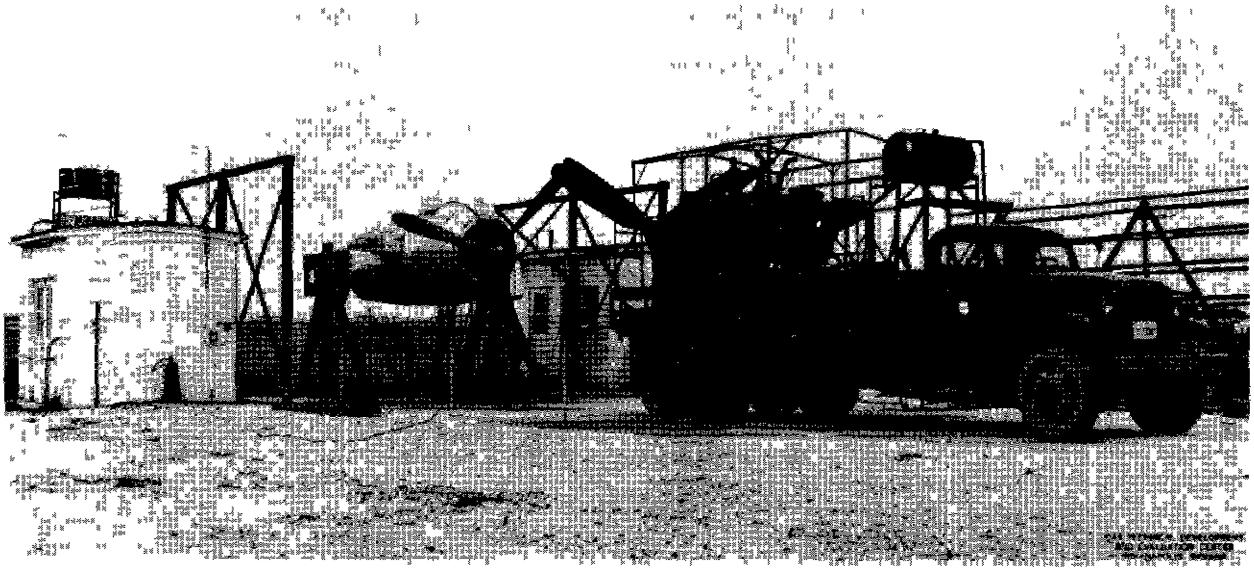


Fig. 1 CV-340 Test Installation

discharge of approximately 1/3 gpm of gasoline which was ignited by a spark plug. Gasoline was supplied to the nozzles at 18-psi pressure by an auxiliary aircraft-type fuel-booster pump. The flow could be started and stopped remotely by solenoid valves located near the nozzles. High-voltage transformers were used as a power source for the ignitor spark plugs. The fire-nozzle assembly included thermocouples to ascertain whether fires had been successfully ignited.

The fire-detector system subjected to tests was the same as that used in operational aircraft of the CV-340, CV-240, and T-29 types, namely, the Edison Type A. The system was comprised of thermocouple detecting units, a relay panel, and an instrument panel. Electrically, the detecting units were arranged in two circuits of 12 units each. Positionwise, six detector units were located in Zone 1, eight in Zone 2, and ten in Zone 3. The locations are given in Table I.

TEST PROCEDURE

Test fires were produced by burning gasoline as it sprayed from a nozzle at 1/3 gpm. Such fires are small enough to produce no immediate damage to nacelle structure but are large enough to require prompt detection. In each test, a fire was started at a selected location and was allowed to continue burning for ten seconds or until detection occurred, whichever was the shorter period. Delayed detection or lack of detection indicated the need for some change in the system. In the course of the program involving several hundred fires, the most effective locations and the minimum number of units required were determined.

For each point of fire origin, the conditions listed in Table II were simulated.

Fires in Zone 1 were of two kinds (1) those simulating fires resulting from failures in the vicinity of the cylinder heads, and (2) those simulating fires resulting from failures near the crankcase of the engine. The fire paths in the two cases are different, and since either could occur, the detector system had to be capable of operating efficiently regardless of the point of fire origin. For all tests, the fire nozzles were located aft of the rear row of engine cylinders. The reason they were so located was to keep the fire damage to a minimum and thus to preclude the possibility of any change in the normal air-flow pattern during the course of the test program. Hundreds of individual tests were conducted to obtain a composite picture of fire paths around the entire engine.

After the first few fires were ignited and observed in Zone 1, there was reason to believe that the main paths of many fires originating in Zone 1 were through the augmenter

TABLE I

ORIGINAL FIRE-DETECTOR LOCATIONS IN THE CV-340 TEST INSTALLATION

Circuit	ZONE 1	ZONE 2	ZONE 3
A	Top Left Cowl-Flap Opening	Top Left Air Vent	Total of Eight Units
A	Top Right Cowl-Flap Opening	Top Right Air Vent	
B	Side Panel of Engine Shroud Upper Left	Lower Shroud Left	
B	Side Panel of Engine Shroud Upper Right	Lower Shroud Right	
B	Bottom Left Cowl-Flap Opening	Upper Mount Tube, Left	Total of Two Units
B	Bottom Right Cowl-Flap Opening	Upper Mount Tube, Right	
B		Lower Mount Tube, Left Junction Box	
B		Lower Mount Tube, Right	

tubes. In order to obtain a more thorough knowledge of the actual conditions inside Zone 1, various aids were employed. First, a continuous-type detecting element was mounted around the bellmouths of the augmenters and across the cowl-flap openings to intercept flames leaving through these exits. Later, light-weight copper screen was used to cover the annular gaps between each bundle of exhaust pipes and the bellmouths. Fires passing down the augmenter tubes burned holes through the screen where the flame paths intersected the screen barriers but left the screen areas adjacent to the paths intact. In other tests, Albi-RX paint was applied to the bellmouths and adjacent surfaces. Wherever flames impinged upon this heat-resistant paint, it expanded into a thick crust and peeled off.

Fires in Zone 2 were the same size as those in Zone 1 and were originated at points generally distributed throughout the zone. In most tests the fires were ignited as soon as the gasoline started to spray from the end of the nozzles, but in a few tests the gasoline was allowed to spray for 20 or 30 seconds before being ignited. A larger fire resulted momentarily in the latter case, but the danger of explosion was much greater. This condition was studied because it could occur in normal flight.

Thermocouples connected to recording potentiometers were used extensively in Zone 2 to assist in tracing the fire paths because fires inside the nacelle were not visible to the crew conducting the tests. The thermocouples were easily moved about and consequently were helpful in determining the relative effectiveness of each point where fire detectors had been located as well as in searching out other areas which might be more effective.

TABLE II

FIRE CONDITIONS

	Engine (rpm)	Cowl Flaps	Simulated Flight Speed (mph)*	Oil-Cooler Flap
1. Taxi	1200	full open	20	full open
2. Cruise	2000	closed	160	closed
3. Take-off	2700	trail	160	full open
4. **	2700	full open	160	full open

* Static pressure in Zone 2 was equal to that in flight at 160 mph at 10,000 feet altitude.
**Condition No. 4 was not a normal operating condition but was used in connection with the tests in Zone 2 because it proved to be the most adverse condition for detecting a fire in that zone while the engine was in operation. It was not used during the fire tests in Zone 1.

RESULTS AND DISCUSSION

The procedure followed in evaluating the CV-340 fire-detection system was to study the behavior of the system under a variety of operating and fire conditions and then, by additional testing, to determine what modifications if any would be desirable.

Approximately 100 fires were started in Zone 1 and an equal number were started in Zone 2 to make the initial study. All regions of possible fire origin were investigated, and for each fire location three or four engine-operating conditions were simulated. The results of the tests in Zone 1 are given in Table III. A detector system was considered adequate if each fire at each operating condition was detected by either circuit A or circuit B or by both. However, it can be seen from an examination of Table III that several fires were undetected all of the time and others were undetected at least part of the time. The results of the Zone 2 tests were not tabulated because rapid detection occurred for nearly all fires.

The normal position of the cowl flaps of the CV-340 power plant during cruising conditions is closed. A fire originating within the engine section, therefore, cannot emerge through the cowl-flap openings and usually is not visible from the outside. For ground operations and for take-off, the cowl flaps are fully or partly open. Fires in certain areas may exit through the flap openings in these cases. However, there appears to be a much stronger tendency for flames to follow the main air flow through the augmenters. These facts were verified during the preliminary tests.

The original fire-detector system which was being evaluated included some detecting units in the cowl-flap openings but no units in the augmenters. Much of the testing in Zone 1, therefore, was concerned with the proper location of units in the bellmouths of the augmenters. Copper screen and Albi-RX paint were the principal means employed to determine fire paths. The results of the tests are shown in Figs. 2, 3, and 4. The clock designations shown in the photographs and used in the text refer to the locations of the fire nozzles or detectors as viewed from the propeller end of the engine. In all other instances (left and right nacelles, left and right augmenter tubes, and so forth), the normal aircraft designations are used, that is, as viewed from the pilot's position.

Figure 2 is a view of the test installation and shows the right augmenter bellmouth after a single fire had burned a hole through the screen. The fire originated aft of the cylinders at the 9 o'clock position. The hole made by the fire is approximately seven inches long The test conditions are shown on the slate. Figure 3 shows the extent of the screen destruction caused by fires originating at the 8-, 9-, and 10-o'clock positions. These established the range within which fire detectors would be most effective in the right bellmouth. Approximately one-half of the screen outboard of the exhaust stacks was burned away.

The upper limiting location for a detector unit in the right bellmouth was established by a cylinder-head fire originating at 11 o'clock. Fires originating near the cylinder heads tended to spread farther around the top than those originating at the crankcase. Subsequent tests established the fact that fires starting at the 12-o'clock position could be detected more quickly by the detectors located on each side of the engine-shroud carburetor bonnet than by

TABLE III

PERCENTAGE OF DETECTION OF ZONE 1 CYLINDER-HEAD FIRES BY ORIGINAL DETECTOR SYSTEM

Fire Location (o'clock position viewed from propeller end)	Engine-Operating Condition*					
	Circuit A Detection			Circuit B Detection		
	1	2	3	1	2	3
	(per cent)			(per cent)		
12 00	0	0	0	17	0	0
11 00	85	57	29	29	0	0
10 00	50	50	0	50	0	0
9 00	25	0	0	25	33	0
8 00	0	0	0	100	50	0
7 00	0	0	0	88	67	83
6 00	0	0	0	100	100	100
5 00	20	0	0	80	60	40
4 00	0	0	0	100	100	100
3 00	50	0	0	50	50	0
2 00	100	100	100	0	0	0
1 00	40	20	0	0	0	0

*Engine Operating Condition 1 - 1200 rpm with cowl flaps full open
Engine Operating Condition 2 - 2000 rpm with cowl flaps closed
Engine Operating Condition 3 - 2700 rpm with cowl flaps in trail position

units in the bellmouths. Fires at the 7-o'clock point of origin were more satisfactorily detected by a unit located in the lower right cowl-flap opening. Fires originating on the left side of the engine burned through the outboard side of the screen on the left bellmouth. The fire-path limits were approximately from 11 30 clockwise to 6 30 o'clock in the left augmenter and from 11 30 counterclockwise to 4 30 o'clock in the right augmenter.

Fire detectors were located in the bellmouths in accordance with the results obtained in the tests. Additional tests were then conducted to observe the operation of the detectors. As an added check of the fire paths during this period, the bellmouths and adjacent areas were painted with Albi-RX. Figure 4 shows the right bellmouth with detectors mounted in it. The photograph also shows that the Albi-RX was affected in approximately the same area where the screen was burned away in the previous tests. Albi-RX at the top and inboard sides of the bellmouths was only moderately affected by the flames. With the detectors mounted in the bellmouths, the units in the upper cowl-flap openings were not necessary and were removed. However, the two units in the lower cowl-flap openings were retained without change. The two units originally mounted on the left and right side panels of the engine shroud were moved upward to the left and right sides of the carburetor bonnet. The final recommended detector locations in Zone 1 are shown in Figs. 5 and 6.

In order to check what was believed to be a fully developed system for Zone 1, another series of tests was conducted in which the fires were started in all regions where fires could logically occur. Four selected power settings and flight conditions were simulated during these tests. The results obtained by starting one fire at each location and under each test condition are summarized in Tables IV and V. The tables show that every fire was successfully detected either by circuit A or by circuit B, or by both circuits. Due to the fact that detector units mounted on the bellmouths of the augmenters were in close proximity to the hot exhaust

Fig. 2 View of Right-Hand Bellmouth (Burned area of copper screen defines flame path and extent)

stacks and gases, there appeared to be a strong possibility that an alarm might be sounded with no fire present during propeller reversal upon landing if such a system were installed in an airplane. Simulation of this condition without a frontal air blast from the blower did not cause the detector system to give a false indication.

The system as modified was considered suitable for installation and flight tests in an operational aircraft. In attempting to make an installation, however, the manufacturer encountered some difficulties and as a result suggested some changes in the detector locations in the bellmouths. Figure 7 shows how the manufacturer's proposed arrangement differed from the TDEC-recommended arrangement. Further tests were arranged to test the two configurations simultaneously. A comparison of the results obtained on a percentage basis for 135 test fires is shown in Table VI.

The testing and modifications required to obtain a satisfactory detection system for Zone 2 were less extensive than for Zone 1. Detection of all fires originating at the points shown in Fig. 8 was successful except for fires originating at points marked 3, 4, 15, 16, 17, and 18. Thermocouples used in the Zone 2 tests helped to establish the most effective locations for the individual units. Figure 9 shows where the detectors were originally located and the changes that were recommended as a result of the tests. Rapid rates of temperature rise were observed in the vicinity of the rear mount brackets for the oil cooler although no detector units were mounted there originally. It was further observed that fires originating in the upper half of the zone were more quickly detected by the two detectors located in the vent door or in the chimney (detectors 1 and 2) than by the detectors located at points 3 and 6. The latter detector units therefore were relocated on the rear mount brackets of the oil cooler. Additional tests showed that the revised arrangement of units in Zone 2 was satisfactory.

Fig. 3 View of Right-Hand Bellmouth (Burned area of copper screen shows flame paths from fires on right side of engine)

More than 800 fires were started in the power plant of the CV-340 test installation in the process of evaluating and improving the detector system. The system as finally developed was capable of detecting most of the fires originating in the nacelle in two to four seconds, although more time was required to detect fires in a few locations. In some instances fires in a particular location under a certain set of conditions would be detected in less than ten seconds, and in other instances the detection of these fires would require a longer period. This accounts for the fact that the percentage of detection appears to be less than 100 in Table VI. However, the system was capable of detecting all fires originating within Zones 1 and 2.

CONCLUSIONS

1. The Edison Type A fire-detection system currently in use in CV-340 type aircraft can be greatly improved by relocating two units and adding four units in Zone 1 and by relocating two units in Zone 2.
2. A CV-340 fire-detection system modified in accordance with the recommendations of this report, when properly installed and maintained, may be expected to detect all fires originating within Zones 1 and 2 and usually within two to four seconds.
3. There is a strong tendency for fires originating in Zone 1 to exit by way of the augmenters.
4. The bellmouths of the augmenters are more effective locations for units than are the upper cowl-flap openings.
5. Detector units are required in the lower cowl flaps to detect fires which originate in the lower part of Zone 1.

Fig. 4 View of Right-Hand Bellmouth (Area where white paint is burned away shows flame paths from fires on right side of engine crankcase)

6. The main paths of fires leading into the augmenters are outboard of the exhaust stacks.

7. Detectors originally mounted on the side panel of the engine shroud are more effective when relocated on the sides of the carburetor bonnet.

8. Detecting units mounted on the bellmouths of the augmenters showed no tendency to alarm falsely because of propeller reversal.

9. Detection is much improved in Zone 2 by placing units near the oil cooler.

10. The TDEC-recommended system is more efficient than the Convair-revised system.

RECOMMENDATIONS

1. Any system incorporating detectors in the augmenter bellmouths should be flight-tested before being adopted for general use on CV-340 or other similar types of aircraft.

2. Any changes to the currently used system should be made in accordance with the revised recommendations shown in Figs. 5, 6, and 7.

TABLE IV

SUMMARY OF PERFORMANCE DATA OBTAINED
WITH REVISED DETECTOR SYSTEM
(Simulated Cylinder-Head Fires in Zone 1)

Fire Location (o'clock position viewed from propeller end)	Engine-Operating Condition*							
	Circuit A Results				Circuit B Results			
	1	2	3	4	1	2	3	4
12 00	O	O	O	O	X	X	X	X
11 00	X	X	X	X	X	O	O	O
10 00	X	X	X	X	O	O	O	O
9 00	X	X	X	X	O	O	O	O
8 00	X	X	X	X	X	O	O	O
7 00	O	X	O	O	X	X	X	X
6 00	O	O	O	O	X	X	X	X
5 00	O	O	O	O	X	X	X	X
4 00	X	O	X	X	O	X	O	O
3 00	X	X	X	X	O	O	O	O
2 00	X	X	X	X	O	O	O	O
1 00	O	O	O	X	X	X	X	O

*X - indicates that the fire was detected
O - indicates that the fire was not detected
Engine-Operating Condition 1 - 1200 rpm with cowl flaps full open
Engine-Operating Condition 2 - 2000 rpm with cowl flaps closed and ram air to carburetor
Engine-Operating Condition 3 - 2000 rpm with cowl flaps closed and carburetor preheat
Engine-Operating Condition 4 - 2700 rpm with cowl flaps in trail position

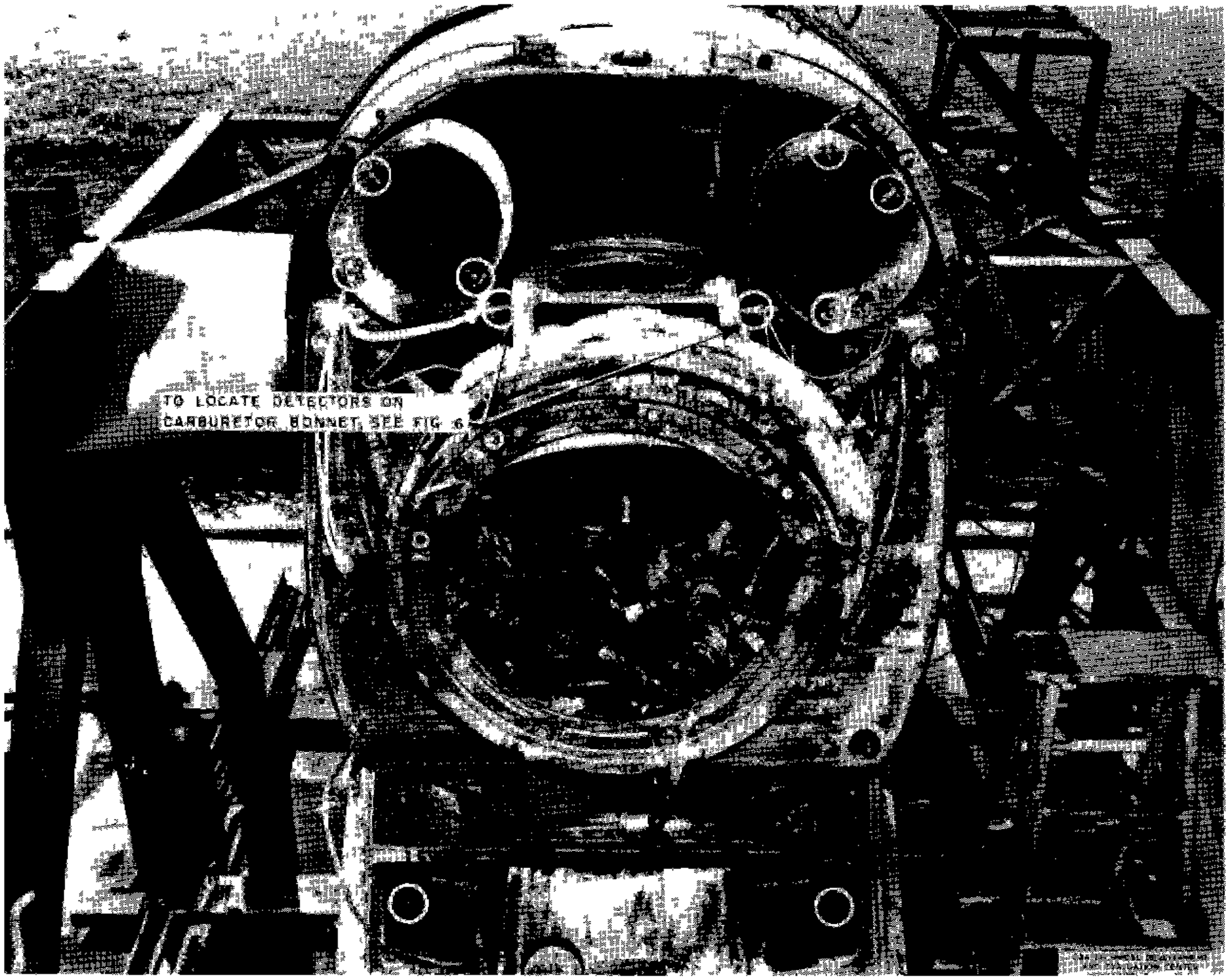


Fig. 5 View of Nacelle Less Engine (Showing recommended locations for Zone 1 fire detectors)

TABLE V

SUMMARY OF PERFORMANCE DATA OBTAINED
WITH REVISED DETECTOR SYSTEM
(Simulated Crankcase Fires in Zone 1)

Fire Location (o'clock position viewed from propeller end)	Engine-Operating Condition*							
	Circuit A Results				Circuit B Results			
	1	2	3	4	1	2	3	4
12 00	O	O	O	O	X	X	X	X
11 00	X	X	X	O	X	X	X	X
10 00	X	X	X	X	O	O	O	O
9 00	X	X	X	X	O	O	O	O
8 00	X	X	X	X	O	O	O	O
7 00	X	X	X	O	X	O	O	X
6 00	O	O	O	O	X	X	X	X
5 00	X	X	X	X	O	O	O	X
4 00	X	X	X	X	O	O	O	O
3 00	X	X	O	X	X	X	X	X
2 00	X	X	X	X	O	O	O	O
1 00	X	X	O	X	X	X	X	X

*X - indicates that the fire was detected
O - indicates that the fire was not detected
Engine-Operating Condition 1 - 1200 rpm with cowl flaps full open
Engine-Operating Condition 2 - 2000 rpm with cowl flaps closed and ram air to carburetor
Engine-Operating Condition 3 - 2000 rpm with cowl flaps closed and carburetor preheat
Engine-Operating Condition 4 - 2700 rpm with cowl flaps in trail position

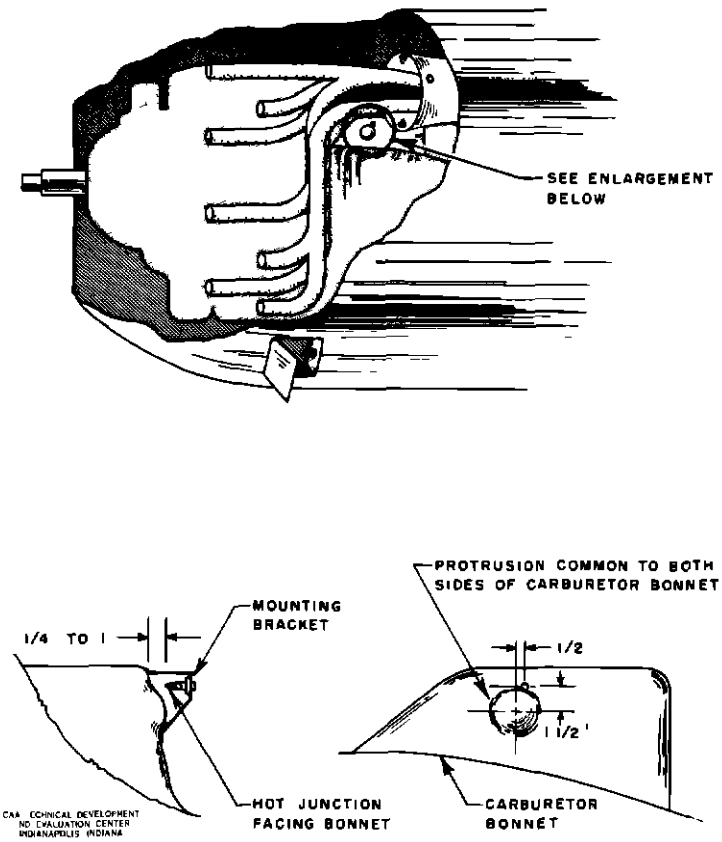


Fig. 6 Carburetor Bonnet Detector Location (One detector on each side of bonnet)

TABLE VI

COMPARISON OF TEST DATA OBTAINED WITH
TDEC RECOMMENDED SYSTEM AND WITH CONVAIR RECOMMENDED SYSTEM

Engine rpm	Cowl-Flap Position	Oil-Cooler-Flap Position	Cylinder Head Fires: Total Fire Tests	Cylinder Head Fires: Per Cent Detection (TDEC System)	Cylinder Head Fires: Per Cent Detection (Convair System)	Crankcase Fires: Total Fire Tests	Crankcase Fires: Per Cent Detection (TDEC System)	Crankcase Fires: Per Cent Detection (Convair System)
1200	Full Open	Full Open	18	100	83.5	27	100	100
2000	Full Closed	Full Open	18	89	83.5	27	85	74
2700	Trail	Full Open	18	89	67	27	74	74

Note See text for explanation of why indicated per cent of detection is less than 100.

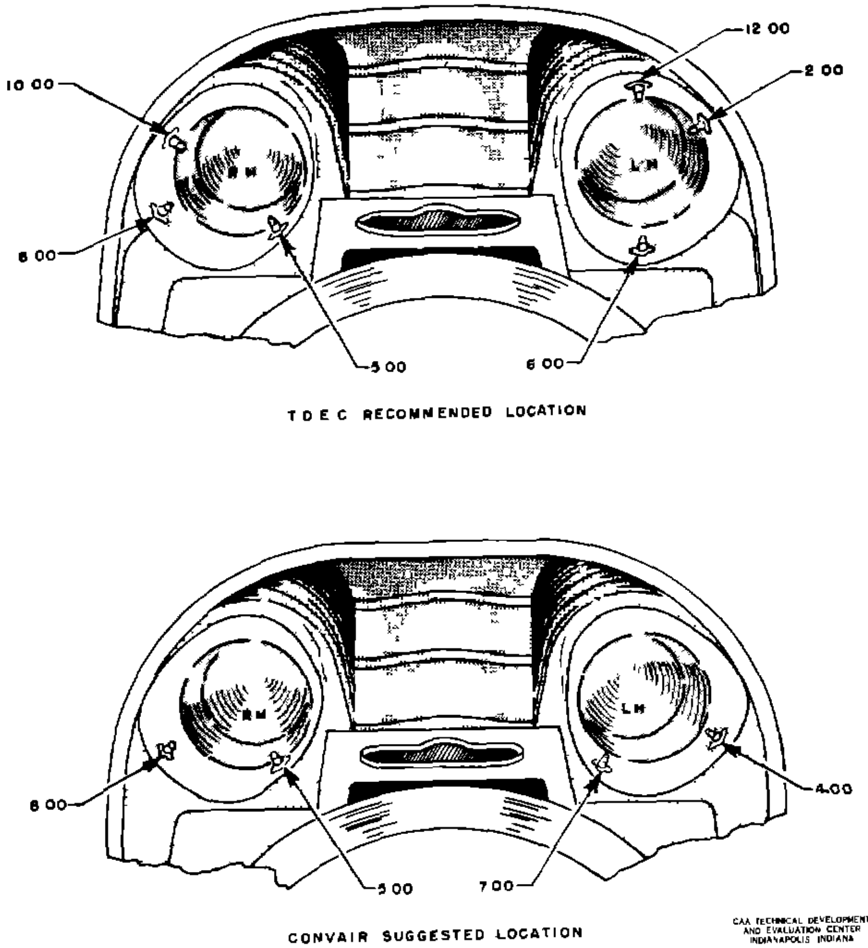
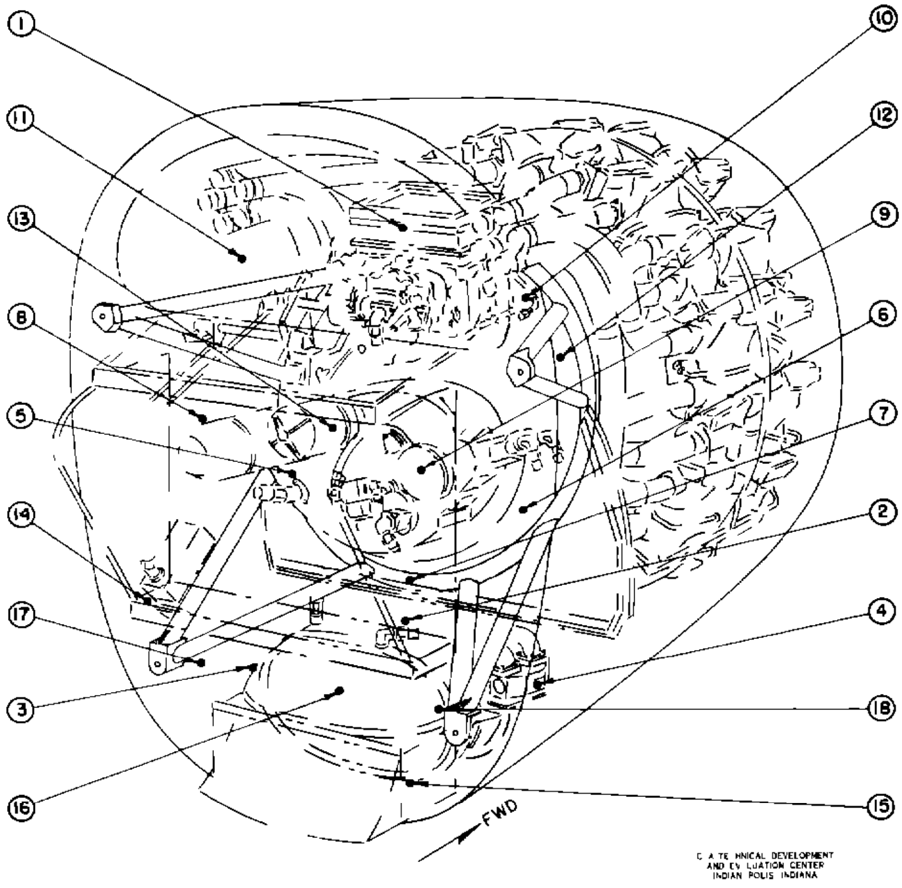


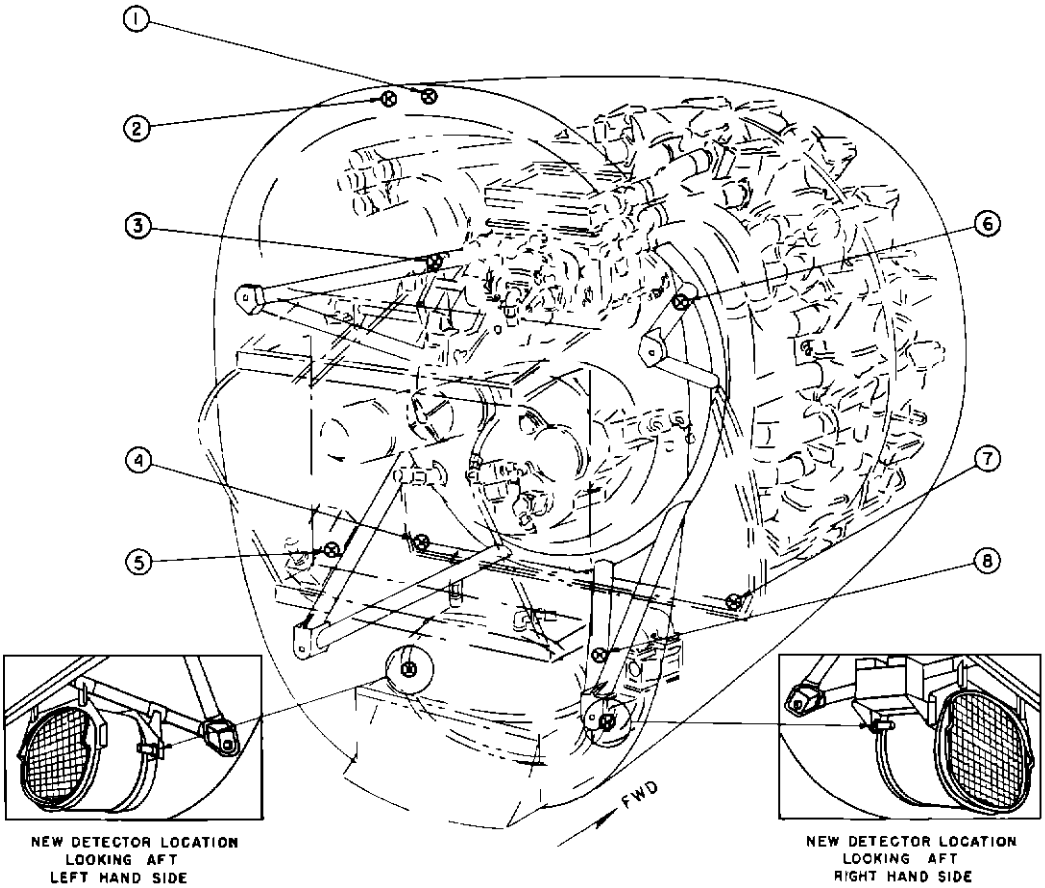
Fig. 7 Locations of Detector Units in the Augmenter Bellmouths of the Convair-340



FIRE NOZZLE POSITIONS

1 ONE FOOT BELOW EXIT PORT
2 AFT OF INLET PORT
3 LEFT SIDE OIL COOLER
4 RIGHT SIDE OIL COOLER
5 BETWEEN GENERATOR & STARTER (4 BELOW GEN)
6 ONE FOOT BELOW HYDRAULIC PUMP
7 FORWARD OF INLET DUCT
8 LEFT OF GENERATOR-POINTING FORWARD & UP
9 TAKE-OFF PAD-POINTING AT ACCESS DOOR
10 RIGHT SIDE FORWARD OF CARBURETOR
11 HIGH LEFT SIDE-POINTING DOWN
12 HIGH RIGHT SIDE-POINTING DOWN & FORWARD
13 RIGHT OF STARTER- TO TOP ACCESS DOOR
14 LEFT SIDE BOTTOM-MATING SURFACE ACCESS DOOR
15 FORWARD-UNDER OIL COOLER SHELL
16 CENTER LOW-FORWARD OF FIRE WALL
17 LEFT SIDE LOW-FORWARD OF FIRE WALL
18 RIGHT SIDE LOW-FORWARD OF FIRE WALL

Fig. 8 Test Fire Locations in Zone 2



THE DETECTORS NUMBERED ARE SHOWN AS POSITIONED IN THE ORIGINAL INSTALLATION
DETECTORS LOCATED AT 3 AND 6 WERE RELOCATED AT THE OIL COOLER REAR
MOUNT BRACKET ON THE LEFT AND RIGHT HAND SIDE AS SHOWN IN THE ABOVE INSETS

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Fig. 9 Zone 2 Detector Locations